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Technical Report No. 32-618

Surveyor Lander Mission and Capability

Milton Beilock

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August 1, 1964

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A handwritten signature in cursive script, reading "W. E. Giberson", positioned above a horizontal line.

W. E. Giberson,
Surveyor Project Manager

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

August 1, 1964

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ABSTRACT

The organization, purpose, and general engineering nature of the *Surveyor* lunar soft-lander project is reviewed in the context of unmanned lunar exploration and anticipated needs of manned lunar programs. Flight and lunar-surface operations are discussed for both the test missions and the operational missions. An estimate of the nature and capability of the engineering payload and each experiment of the scientific payload is presented. Finally, a brief discussion of the possibilities of follow-on missions is given.

28969

Author

I. INTRODUCTION

What the writer proposes is, in brief, to take his readers on a guided tour of the store of the principal items of information concerning the physical properties of our satellite and the conditions prevailing on its surface—obtained, to be sure, not yet from an autopsy, but rather by telescopic examination, at a distance which never becomes less than 238,000 miles. In spite of this rather wide gap of space separating us from the Moon, our knowledge of the conditions obtaining on its surface is remarkably complete—in particular, we may already be actually in possession of most part of the information which the first intrepid interplanetary travellers of the future, stepping out of their space ships, will need in order to have a fighting chance of survival.

—Z. Kopal, "The Moon"

In spite of the promise offered by the above quotation, the managers of both manned and unmanned lunar landing spacecraft development programs are spending more than ten million dollars each day with little more than conflicting data and assumptions available concerning the lunar surface environment. For example, convincing arguments can be obtained from various leading scientists that the lunar surface is either very smooth or very rough; that its structure is either a soft, powdery, loosely-

packed dust or extremely hard rock; that its mass is increasing due to meteoric impacts or that it is decreasing due to secondary ejecta resulting from these impacts.

Until now, and in the foreseeable future, Earth-based observations can only be used to postulate the possible selenological origins and, hence, gross characteristics of relatively large areas of the lunar surface. Confirmation of these postulations and the determination of a true

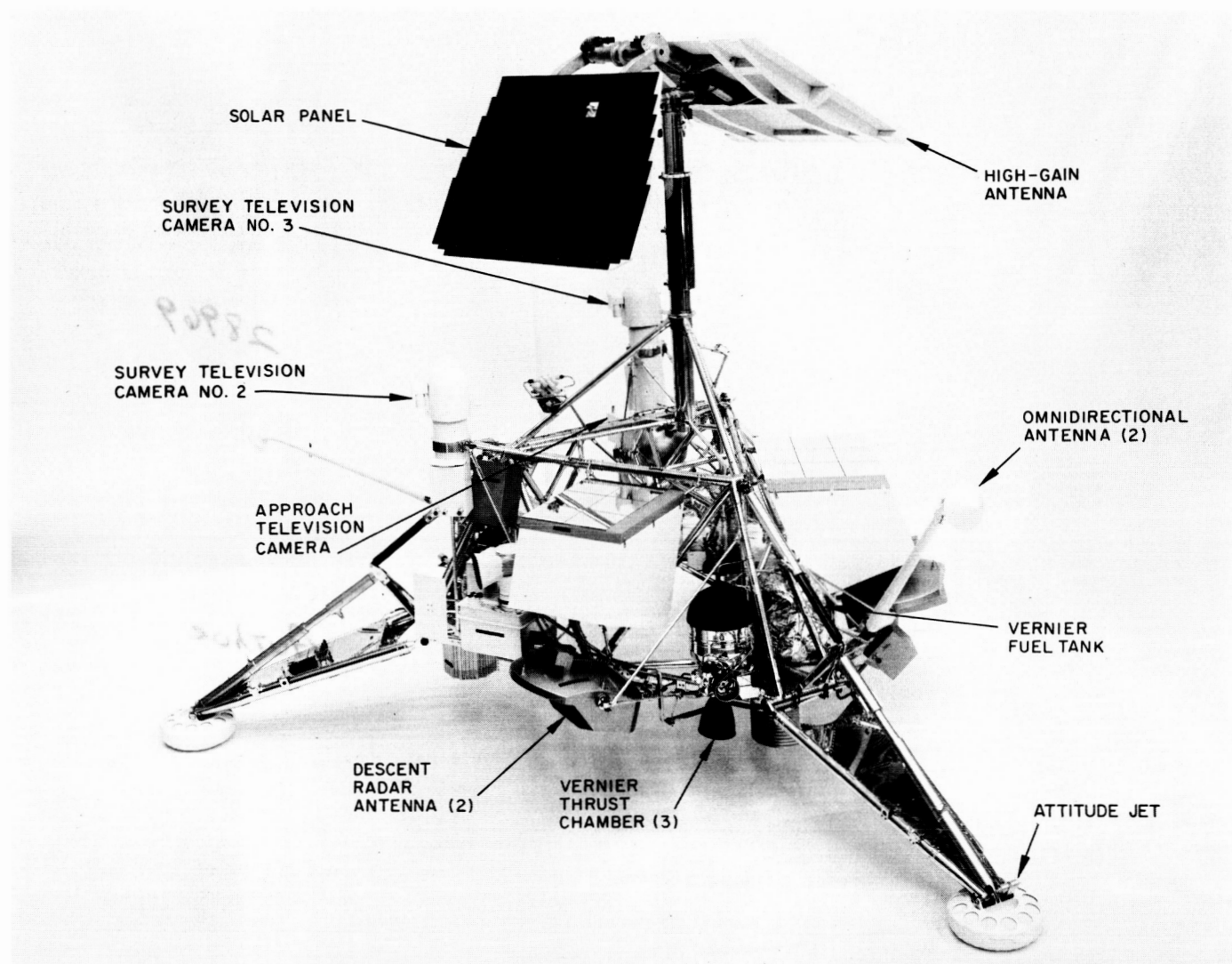


Fig. 1. Surveyor spacecraft operational configuration

lunar model, for which spacecraft can be designed with confidence, appears destined to be accomplished only by experiments conducted on the lunar surface.

In order to conduct the desired experiments, the *Surveyor* unmanned lunar exploration system is being developed. Within the system, the *Surveyor* spacecraft will

transport instruments to the Moon and there function as a remote laboratory completely controllable from Earth (Fig. 1). *Surveyor* will provide demonstrations of a lunar soft-landing technique, surface surveys involving both scientific and engineering measurements, and the means for early and accurate certification of potential Apollo lunar landing sites.

II. SURVEYOR PROJECT

The objective of the *Surveyor* project is the achievement of a successful landing on the lunar surface in 1965, as demonstrated by proper operation of the spacecraft after touchdown. Subsequent to 1965, *Surveyor* is to provide engineering and scientific data which will be used to establish a firm lunar model and contribute to the technology required for the successful accomplishment of later missions, particularly manned landings.

There are seven missions currently authorized in the *Surveyor* program. These are scheduled for 1965 and 1966. An additional ten follow-on missions are presently under study.

The first four *Surveyor* spacecraft will carry an engineering payload designed to provide additional redundancy and furnish diagnostic engineering measurements of subsystem operation during transit and landing. The next three spacecraft will carry a payload composed of scientific instruments. Payloads for the ten follow-on spacecraft are currently being studied to determine how they can best support the Apollo requirements for landing-site surveys while continuing the lunar exploration program.

The *Surveyor* project is managed by the California Institute of Technology Jet Propulsion Laboratory (JPL) for the National Aeronautics and Space Administration (NASA). The project is supported from within NASA by the Lewis Research Center (LeRC) and the Goddard Space Flight Center (GSFC). Within JPL, support is given by the Deep Space Network (DSN), including the Deep Space Instrument Facilities (DSIF), and Space Flight Operations Facility (SFOF). The Hughes Aircraft

Company has been under contract to JPL since March 1961 to develop the spacecraft. General Dynamics/Astronautics is under contract to LeRC to develop the launch vehicle (Fig. 2).

The spacecraft will be boosted to injection by an Atlas/Centaur launch vehicle. Launch and preinjection tracking are provided by the Atlantic Missile Range. During transit to the Moon, the DSN will be used for spacecraft orbit determination and to transmit the necessary commands to effect a midcourse maneuver to minimize landing dispersion. The DSN will also be used to receive engineering and scientific data telemetered from the spacecraft during transit to, and operations on, the lunar surface. After spacecraft injection, all mission operations will be conducted from the SFOF located at JPL. Accumulation of engineering and scientific data and the processing and partial reduction of the scientific data will also be accomplished at this facility. The functional relationship of these systems is shown in Fig. 3.

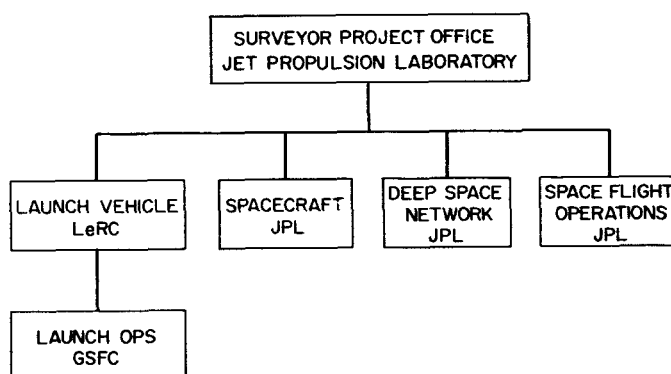


Fig. 2. *Surveyor* project/system organization

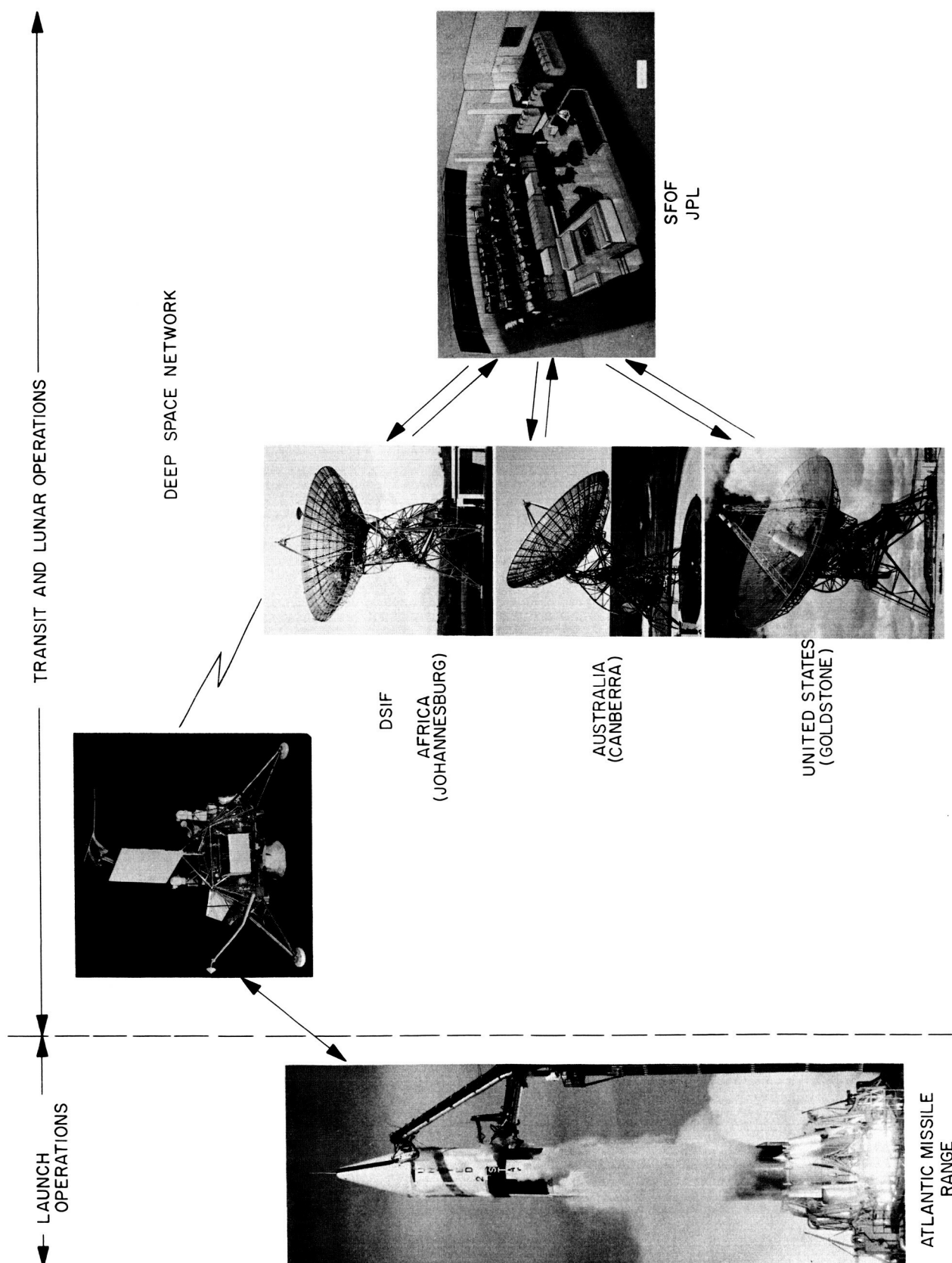


Fig. 3. Surveyor system functions

III. MISSION OPERATIONS

Surveyor missions will originate from Cape Kennedy, Florida. A typical transit sequence is shown in Fig. 4. Upon being boosted to an altitude of approximately 60 mi, the spacecraft shroud will be jettisoned. The spacecraft will then extend its three landing legs and two omnidirectional antenna booms and transmit a radio signal to permit tracking by the three DSIF tracking stations.

After separation of the spacecraft from the Centaur, tracking acquisition occurs at the Johannesburg, South Africa station with later tracking by stations at Canberra, Australia, and Goldstone, California. Three cold gas reaction jets located on the landing gear legs control the spacecraft through an angular search to acquire and track both the Sun and the star Canopus. When the appropriate sensors lock on to these celestial points, an inertial reference system is established in space which is automatically maintained during transit.

Tracking data received in sequence from the three DSIF stations are processed and used to compute any required midcourse correction approximately 20 hr after launch. The magnitude and direction of the midcourse correction is sent from the Goldstone tracking station to the spacecraft, where it is stored. Upon radio command, the spacecraft orients itself along the specified thrust vector, and at the appropriate time, three storable liquid-fueled vernier rocket engines operate to provide a midcourse alteration of the trajectory which will ultimately bring the spacecraft to the chosen lunar landing area. After the midcourse correction is completed, the spacecraft reacquires the Sun and Canopus to maintain its previous attitude.

Approximately 66 hr after launch, *Surveyor* approaches to within 1,000 mi of the lunar surface. Upon command from the Goldstone tracking station, the spacecraft changes attitude to align the thrust of its retrorocket with the computed spacecraft velocity vector. As the

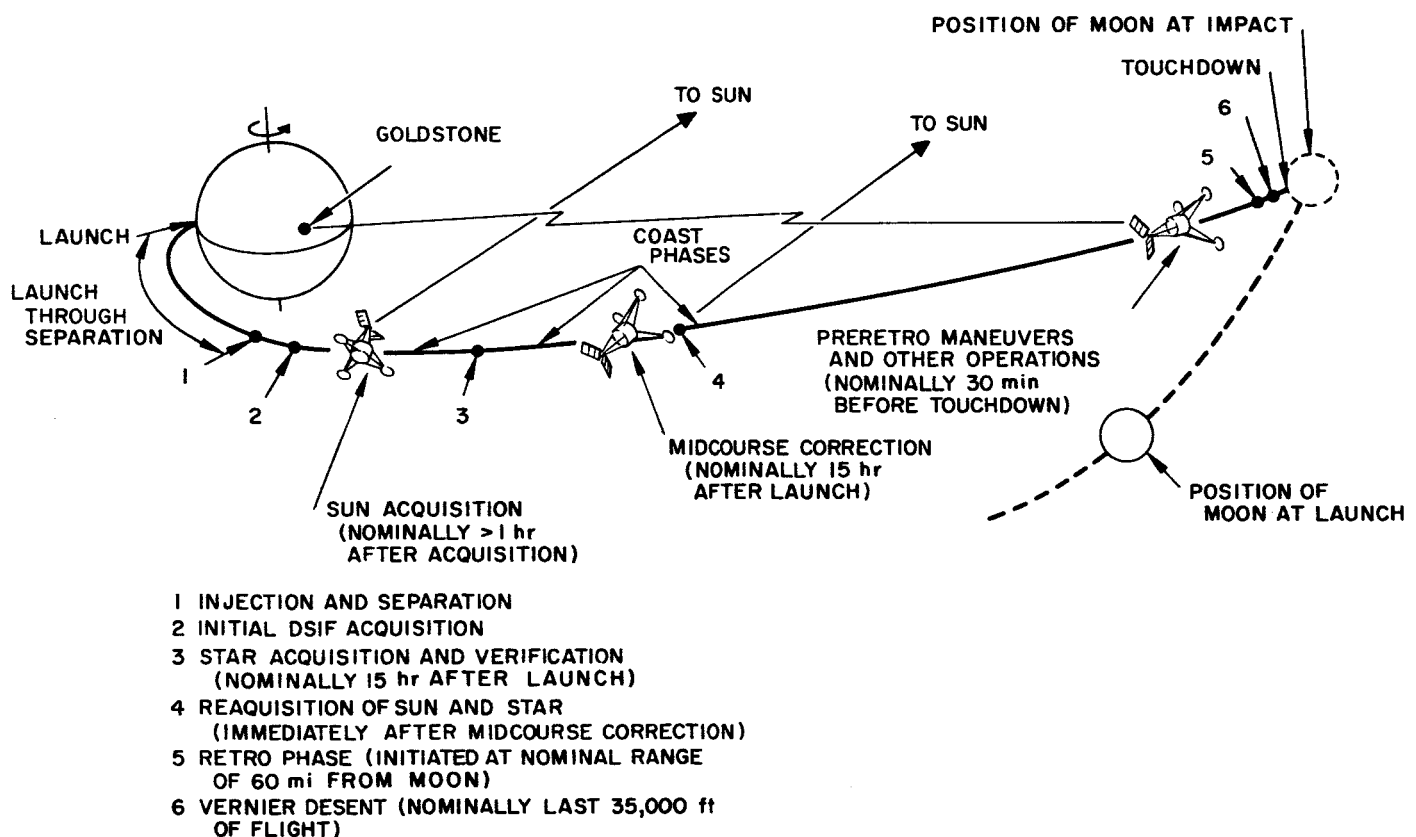


Fig. 4. Earth-Moon transit

spacecraft approaches the Moon at a relative speed of about 9,000 fps, the altitude-marking radar generates a signal at the 60-mi point causing first the vernier engines and then the solid propellant main retrorocket motor to ignite. Main retro ignition expels the radar from the retrorocket nozzle and decelerates the spacecraft. At an altitude of approximately 40,000 ft, the main retrorocket burns out and its empty case is dropped from the spacecraft.

At this point, the spacecraft is close enough to the surface of the Moon to receive a good signal from its radar altimeter and doppler velocity sensor system. Signals from this system are processed by the flight control electronics and used to control the three vernier rocket engines. Thus, the spacecraft continues to decelerate along a preprogrammed range-velocity curve until an altitude of 13 ft is reached. At this time the horizontal and vertical components of velocity are less than 5 and 15 fps, respectively, and the vernier engines are turned off. The spacecraft falls the remaining short distance to the surface of the Moon with the touchdown cushioned by the landing legs and crushable energy absorbers located under the spaceframe.

As the true nature of the lunar terrain is not known, it has been assumed for the purpose of spacecraft design that lunar surface slopes do not exceed 15 deg; protuberances are 10 cm or less; soil compressive strength is greater than 50 psi; and the coefficient of friction with the landing gear foot pads is less than 1.0. Full-scale touchdown dynamics drop tests have shown the spacecraft to be capable of landing on the assumed lunar terrain (Fig. 5).

Once safely landed on the lunar surface, the spacecraft is commanded via its omnidirectional antennas to search in angle to acquire the Sun and Earth with the solar panel and high-gain antenna, respectively. With communications thus established via the high-gain antenna, exploration of the lunar surface begins.

Initial landings are planned to occur near the lunar equator where the spacecraft descent trajectory is nearly

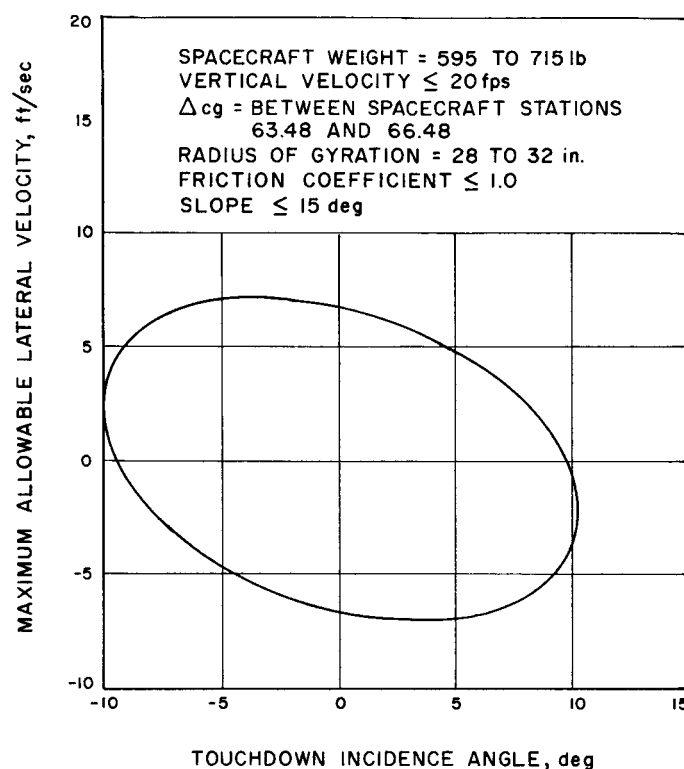


Fig. 5. Lateral touchdown velocity envelope

vertical (Fig. 6). Although *Surveyor* is designed to be capable of landing at unbraked impact angles as high as 45 deg, near-vertical approaches (20 deg or less) have been chosen to maximize the probability of a successful landing. As can be seen in Fig. 6, initial *Surveyor* landings will be made in the area of interest for the Apollo landings.

The location of the spacecraft relative to prominent lunar features can be determined with reasonably good accuracy. If local features at the landing point can be correlated from postlanding television surveys to presently mapped lunar topography, the spacecraft location can be pinpointed to within 200 m. Without this postlanding lunar feature correlation, the landing point should be known to ± 10 km from the orbit determination program, ± 2 to ± 8 km from approach TV data and to ± 3 km from postlanding TV stellar observations.

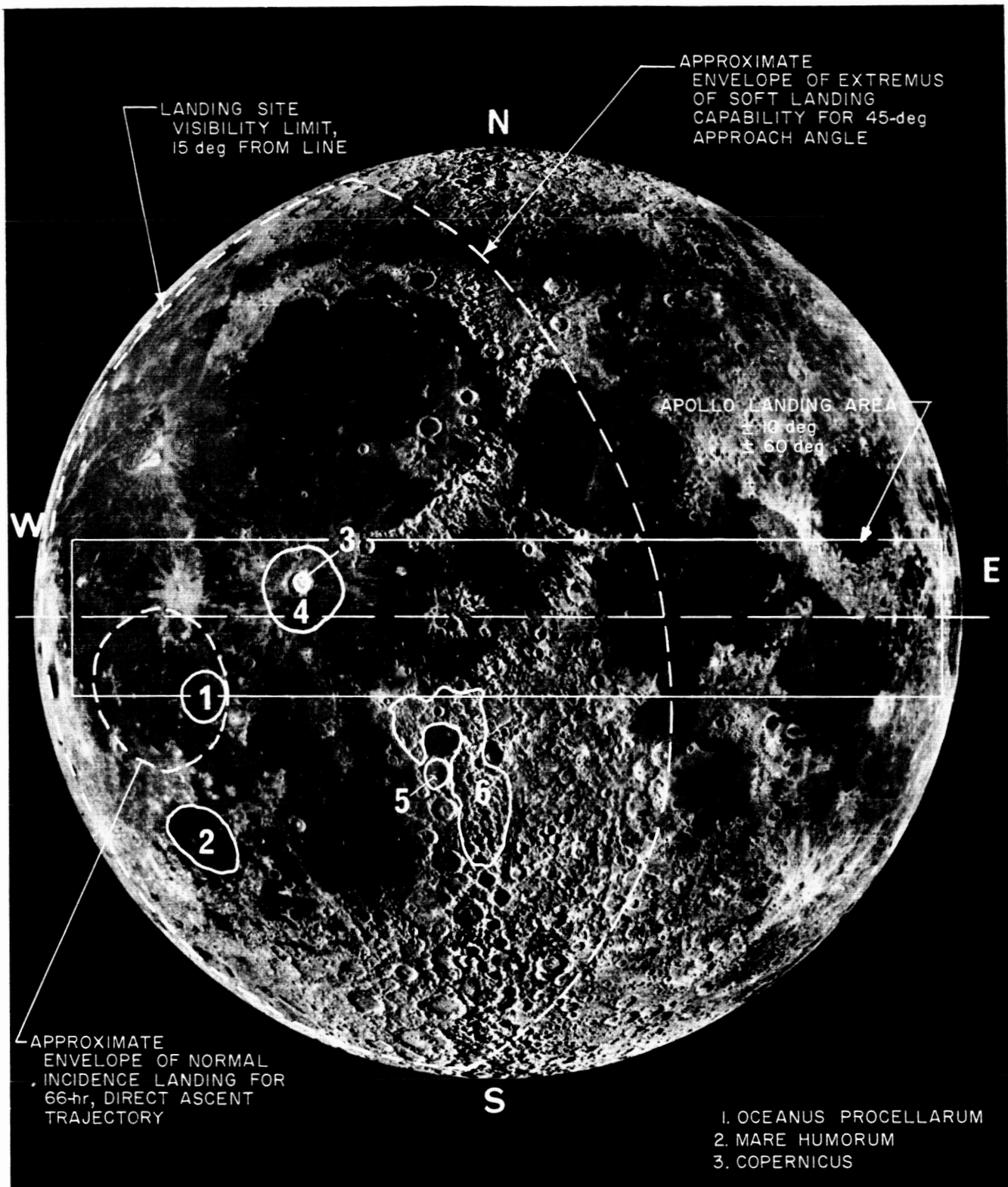


Fig. 6. Lunar landing areas

IV. SPACECRAFT CONFIGURATION AND OPERATION

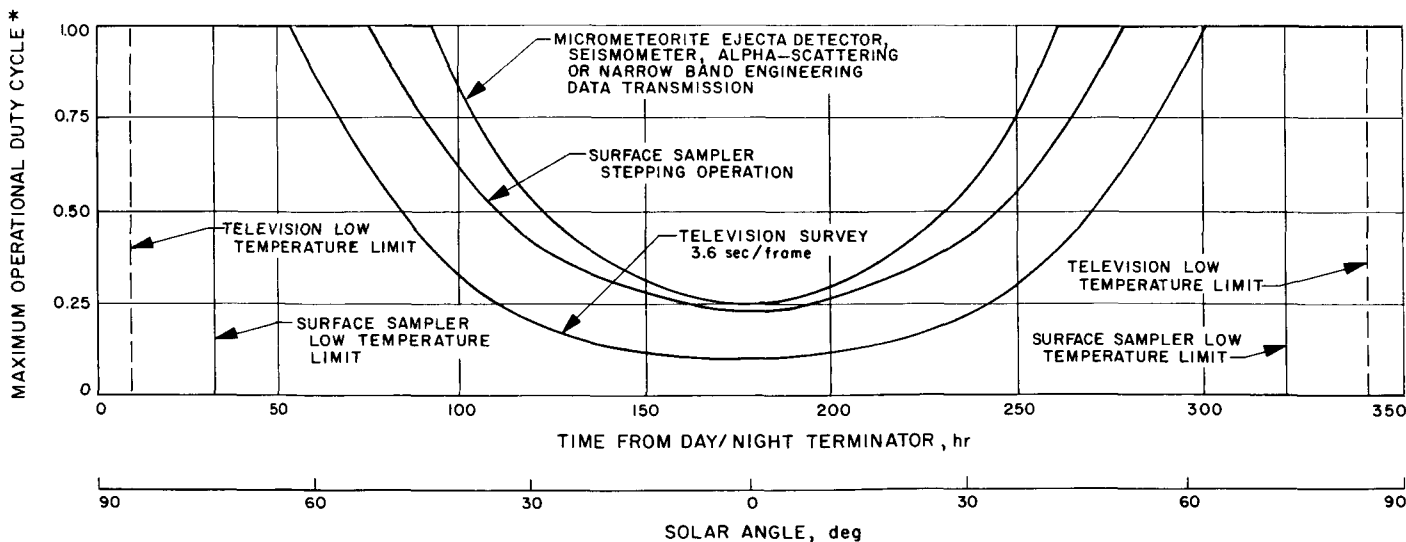
In accordance with its mission objectives, the *Surveyor* spacecraft has been designed to provide common operational needs for as broad a spectrum of payloads as possible. The spacecraft design philosophy has been to maximize the probability of successful spacecraft operations within the basic limitations imposed by launch vehicle capabilities, the extent of knowledge of transit and lunar environment, and the current technological state-of-the-art. In keeping with this philosophy, policies were established early in the program to: 1) minimize spacecraft complexity by placing responsibility for decision-making and control functions on Earth-based equipment where these functions can be performed without being limited by the power, size and weight restraints of the spacecraft; 2) provide the capability for transmission of a large number of different data channels from the spacecraft; 3) include provisions for accommodating a large number of individual commands; and 4) make all subsystems as independent as practicable. These design policies have been found to complement each other and provide an unusual degree of flexibility in controlling the real-time operations of the spacecraft.

While this design concept places somewhat greater demands on Earth-based equipment and facilities, it does provide wide control and data transmission adaptability. Complete control of spacecraft operation is thus

achieved only through a loop that is closed through Earth-based equipment and decision-making processes. The only portions of spacecraft operations that are not subject to this Earth/spacecraft control loop are those associated with certain portions of the attitude stabilization and terminal descent activities, where rapidly occurring critical events do not permit Earth control.

The *Surveyor* spacecraft is considered to be composed of two major items, the basic bus and the payload. The basic bus furnishes all the subsystems and functions required for transport, maintenance, and operation of the payload. The nominal injected gross weight of the *Surveyor* spacecraft is 2,150 lb. Design weight of the basic bus is 692 lb, usable propellants 1,393 lb, and scientific payload 65 lb. It is estimated that the total number of pieceparts for the basic bus alone will be approximately 63,000. Another 15,000 is estimated for the scientific payload instruments, auxiliaries, and mechanisms.

Due to the wide range of lunar surface temperatures anticipated (from approximately $+127^{\circ}\text{C}$ at the subsolar point to approximately -153°C during the lunar night), thermal control of the spacecraft has been one of the more difficult problems. As might be expected, the present solution places limitations on the operational capability of the spacecraft.



*SPACECRAFT THERMALLY CONTROLLED COMPARTMENT CAPABILITY ONLY,
EXTERNAL SENSORS NOT INCLUDED EXCEPT AS SPECIFIED

Fig. 7. Operational capability for equatorial landing

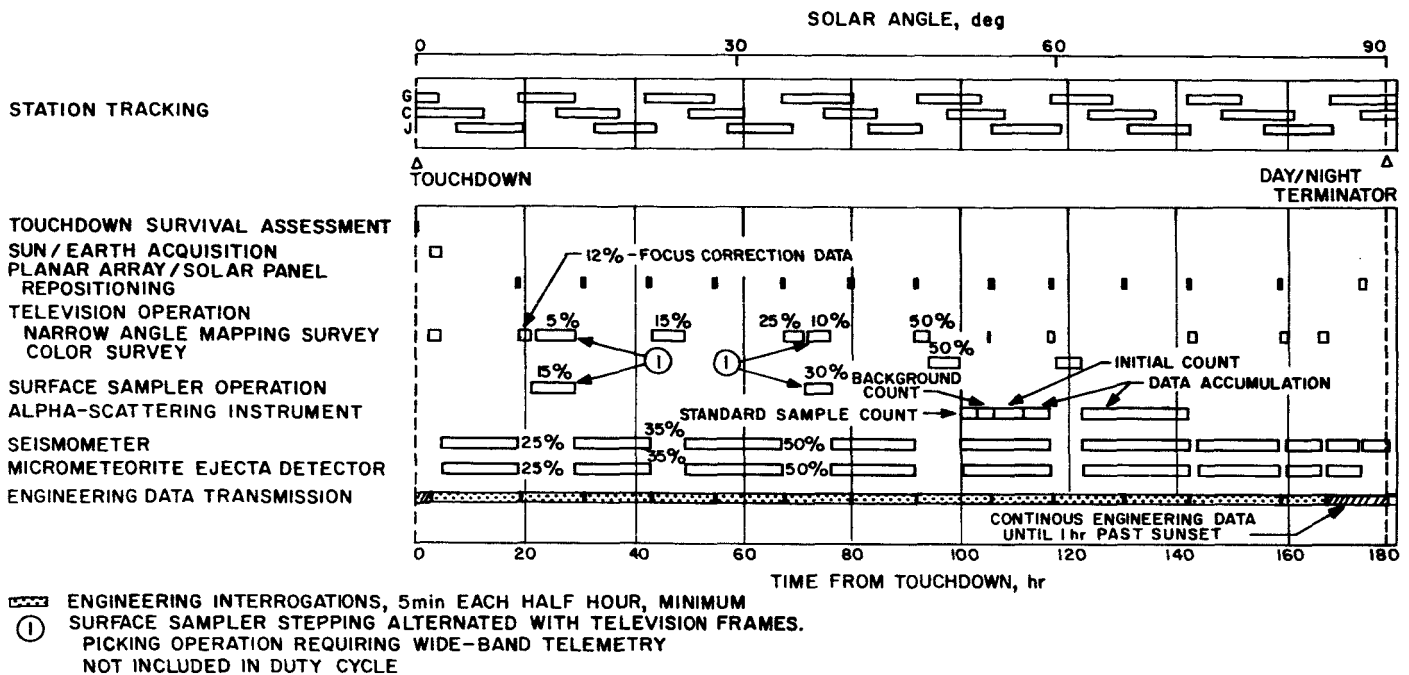


Fig. 8. Typical scientific-payload lunar operations sequence

The lunar day operation capability of Spacecraft 5-7 is described in Fig. 7. The degree to which the available power is utilized depends on the mission sequence of operation and is limited by the capability of the thermally controlled compartments to dissipate the heat generated by the spacecraft subsystems located in them. Spacecraft 5-7 are capable of operating throughout the lunar day. However, due to a lower thermal dissipation capability for Spacecraft 1-4, lunar day maximum operational duty cycle is essentially zero for the period two days prior to and after lunar noon. In general, sufficient energy is available to conduct all desired operations. The single exception would be a landing just prior to sunset, in which case sufficient time may not be available to fully charge the battery before entering the lunar night.

The lunar night operational capability is dependent on the energy available in the batteries and the internal heat dissipation required for the maintenance of the minimum allowable compartment and equipment temperature. Required heat dissipation can be provided by heaters, or more efficiently from an operational standpoint, by using the telecommunications system to transmit data. Theoretically, it can be seen that should the spacecraft enter the lunar night with a fully charged battery (3,200 whr available), it can survive approxi-

mately one-half the night (7 Earth days). However, for the case of an actual night landing, the batteries will be in a partially depleted state (840 whr available) and the spacecraft can only survive for approximately 30 hr.

A typical sequence of operation for the case of an equatorial lunar non-noon landing is shown in Fig. 8. The touchdown survival assessment and the Sun and Earth acquisition by the solar panel and planar array are completed during the first hour. The initial television survey may be conducted by means of predetermined command programs. Subsequent color and mapping surveys could typically provide two color surveys and give 1-hr mapping surveys. The first two typical television surveys consisting of about 1,000 frames each must be interrupted for thermal cooldown of the compartments in accordance with thermal constraints. Sufficient solar energy is available for additional optional surveys which have not been shown. The television operation would also be interrupted each half hour for approximately 5 min so that engineering interrogations for monitoring the spacecraft status could be conducted. Necessary data for attitude determination, Sun and Earth, and two star positions in spacecraft and television system coordinates may be obtained during the initial positioning and television survey.

V. PAYLOAD DESCRIPTION

The objective of the first four *Surveyor* missions is the achievement of a successful landing on the lunar surface, as demonstrated by the operation of the spacecraft after landing. For these missions, the payload has functions specifically associated with determining the performance capabilities and operational readiness of the spacecraft and the entire *Surveyor* system. These functions are provided by an engineering payload which monitors the operation of the spacecraft, provides critical component redundancy, and assists in determining the lunar touchdown conditions. The principal items in the engineering payload are the television survey camera, the auxiliary battery, and additional engineering instrumentation.

A scientific payload is provided for Spacecraft 5-7 which will be used on the first operational missions. The complement of payload items and principal investigators for both the engineering and scientific payloads is given in Table 1. The arrangements of engineering payload and scientific payload items are shown in Figs. 9 and 10, respectively. A description of each of the data-gathering payload items follows.

Table 1. Surveyor payload configurations

Payload item	Engineering payload Spacecraft 1-4 Number of units	Scientific payload Spacecraft 5-7 Number of units	Principal investigator
Sensors			
Thermal*	11		
Stress	7		
Current	2		
Acceleration	4		
Experiments			
TV approach	1	1	
Survey	1	2	E. M. Shoemaker
Soil mechanics		1	R. F. Scott
Alpha-scattering		1	A. Turkevich
Micrometeorite		1	W. A. Alexander
Seismograph		1	G. H. Sutton
Touchdown dynamics		1	S. A. Batterson
*Sixty-three thermal sensors are provided on every spacecraft as part of the basic engineering instrumentation.			

A. Sensors

The engineering payload sensors provide data on the performance of the spacecraft and its response to the environment beyond the capacity of the basic bus instrumentation. Locations of the engineering sensors are shown in Fig. 9. There are, in addition to the 63 thermal sensors provided in the basic engineering instrumentation, 11 temperature sensors, 4 accelerometers, 2 current sensors, and 7 strain gauges. These sensors are provided to gather diagnostic information and are not normally provided on operational flights.

B. Television-Approach Experiment

The approach television system is designed to provide pictures of the spacecraft landing site. During the approach phase (1,000 to 50 mi above the lunar surface), the camera (Fig. 11) provides a center-of-frame optical resolution of 0.5 mrad and a square field of view 6.4 deg on a side. The lunar surfaces exposed to view for 15-, 30-, and 45-deg approach angles are shown in Fig. 12. It can be seen that, with the exception of the initial picture, at least 50% of the lunar surface area in each picture will appear in the preceding picture. One frame can be taken every 3.6 sec, but picture transmission must be time-shared with the engineering data telemetry. The system will be capable of distinguishing at least eight $\sqrt{2}$ gray levels at a highlight luminance of 800 ft-L. An iris adjustment prior to launch will set the system at the optimum sensitivity for expected lunar-scene luminance from 50 to 2,600 ft-L.

C. Television-Survey Experiment

The survey television system will be used after lunar landing for surveillance of the lunar surface and monitoring the operations of other experiments. The survey camera (Fig. 13) is equipped with a variable focal length lens (25 to 100 mm) that can be commanded to provide a 6.4- × 6.4-deg minimum or a 25.6- × 25.6-deg maximum field of view (Fig. 14). In both wide- and narrow-angle modes, the system is capable of 360-deg observation in azimuth, and 20 deg above and 45 deg below the horizontal plane of the spacecraft. Photometric measurement capabilities and frame speed are similar to those of the approach camera. An automatic iris is provided ($f/4$ to $f/22$). Provision is also made for the insertion of colored or polarized filters into the optical path on command.

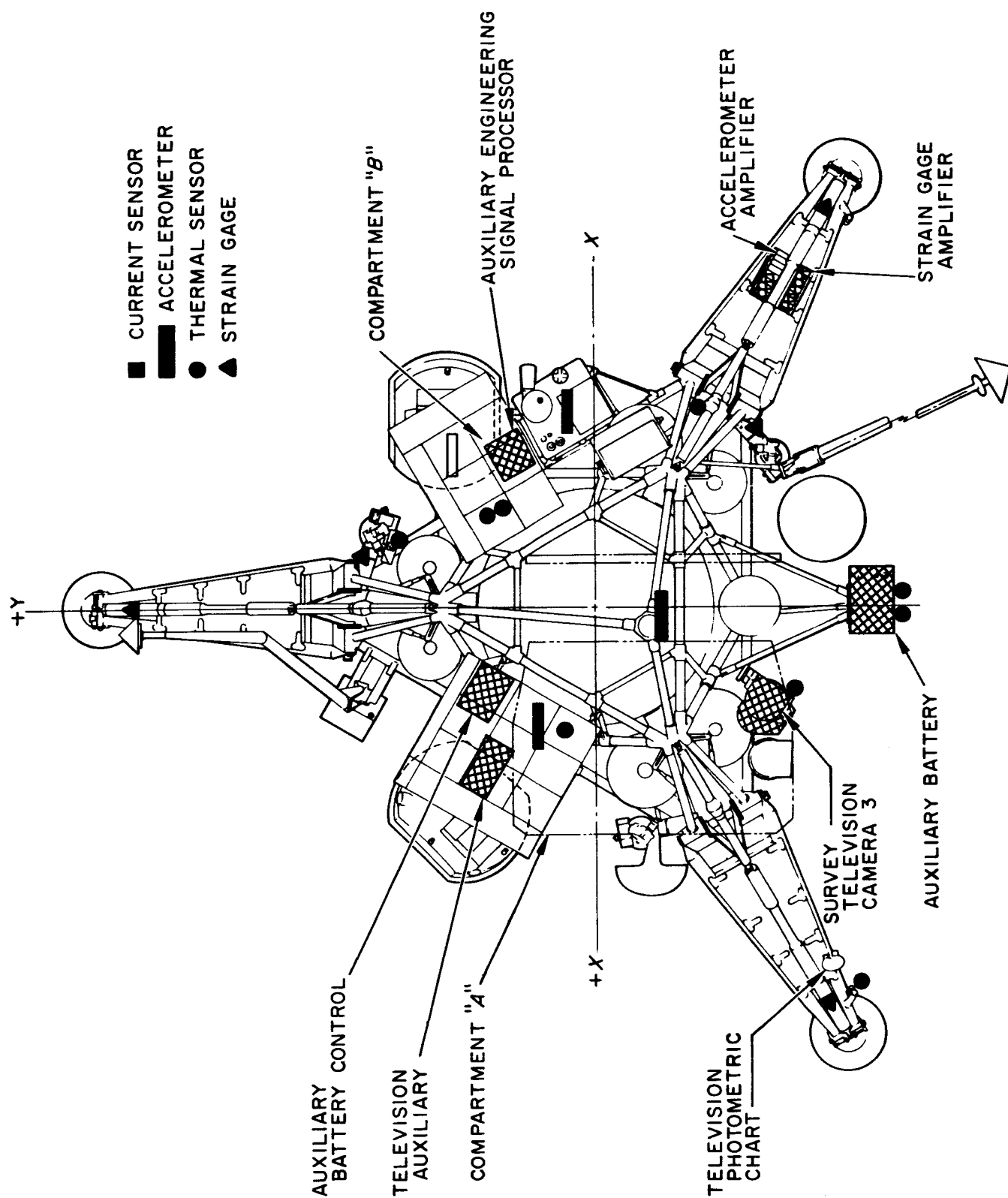


Fig. 9. Engineering payload

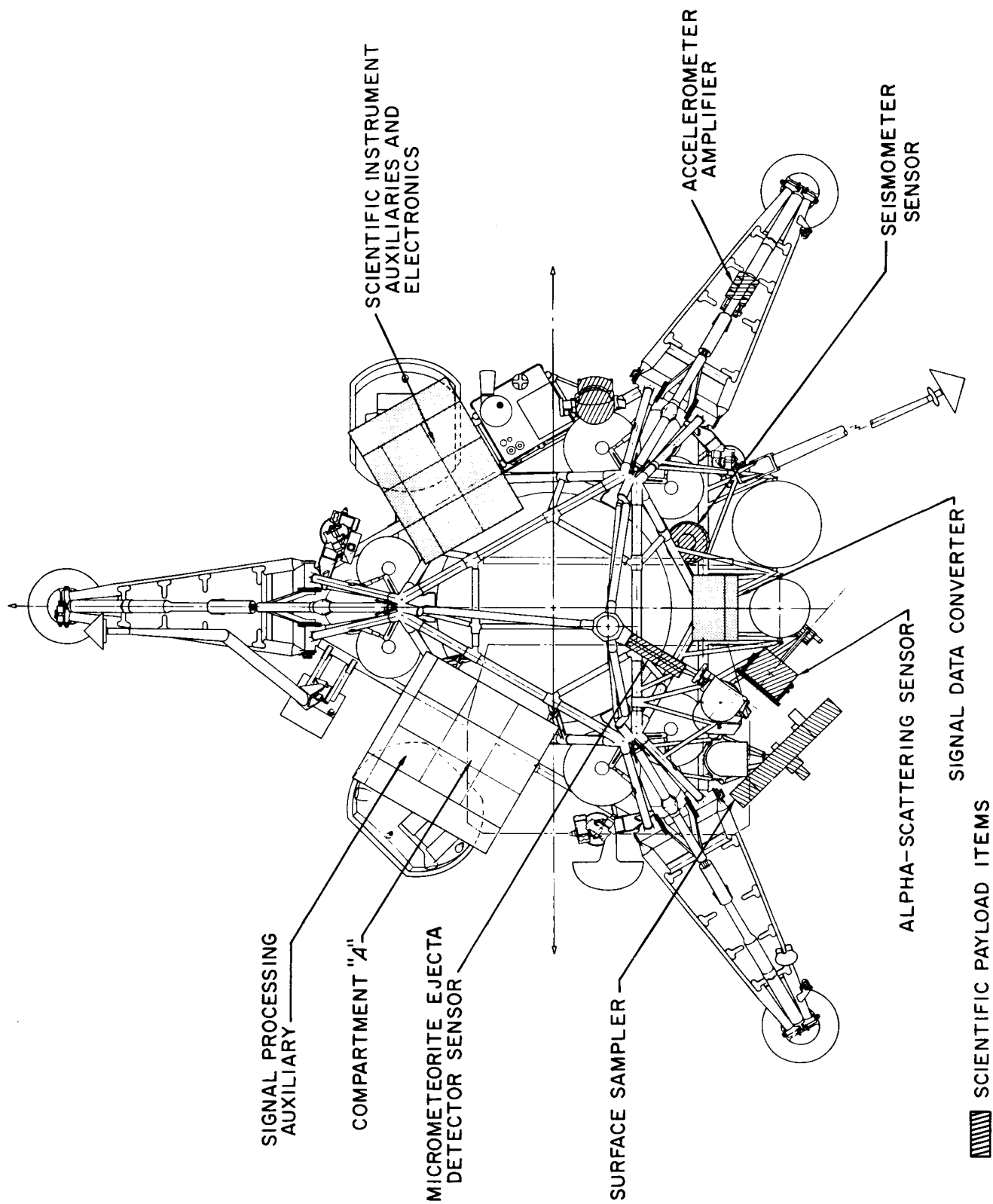


Fig. 10. Scientific payload

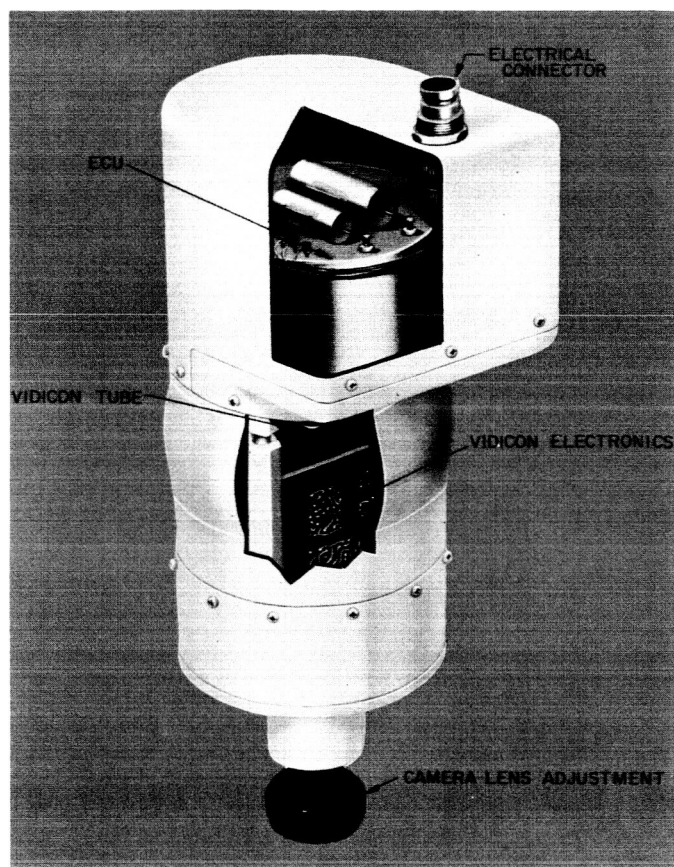


Fig. 11. Approach camera

from Earth. Stereoscopic viewing is provided in the scientific payload through the use of two survey cameras. However, less than one-third of the area visible to these cameras will be observable stereoscopically because of spacecraft obstructions and baseline requirements.

D. Soil Mechanics Experiment

The soil mechanics experiment is designed to determine the nature and mechanical characteristics of the lunar surface. An instrumented mechanical arm, known as the surface sampler, is provided for this experiment (Fig. 15). The surface sampler is capable of providing detailed topographic measurements with approximately ± 0.3 -in. accuracy over a 30-ft² area within its reach of approximately 5 ft. An accelerometer, providing 0 to 50 g and 0 to 2,000 g outputs, is mounted on the scoop to measure deceleration during picking actions. One transducer measures vertical forces of 0.1 to 3.0 lbf, while another transducer measures retroactive forces of 0.1 to 20.0 lbf.

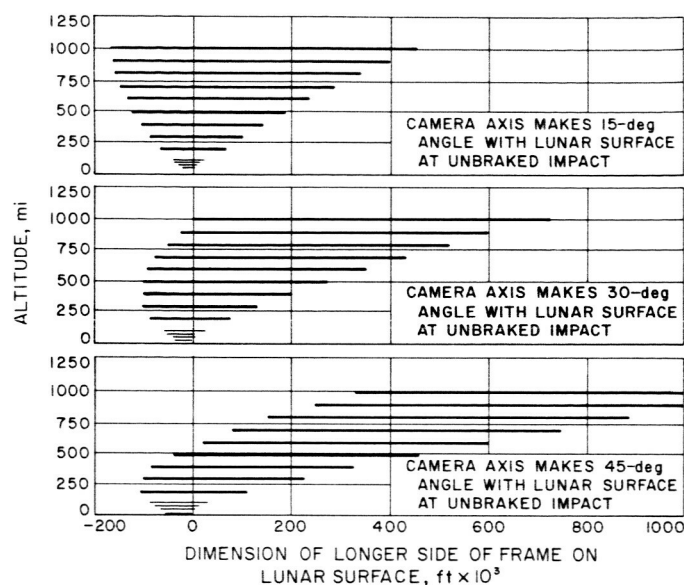


Fig. 12. Approach TV fields of view

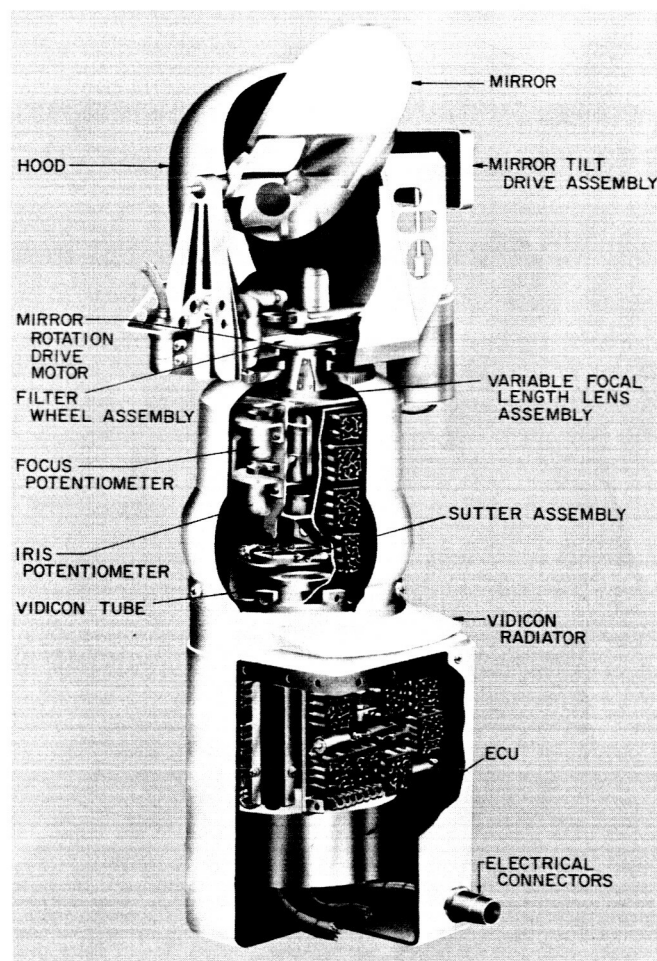


Fig. 13. Survey camera

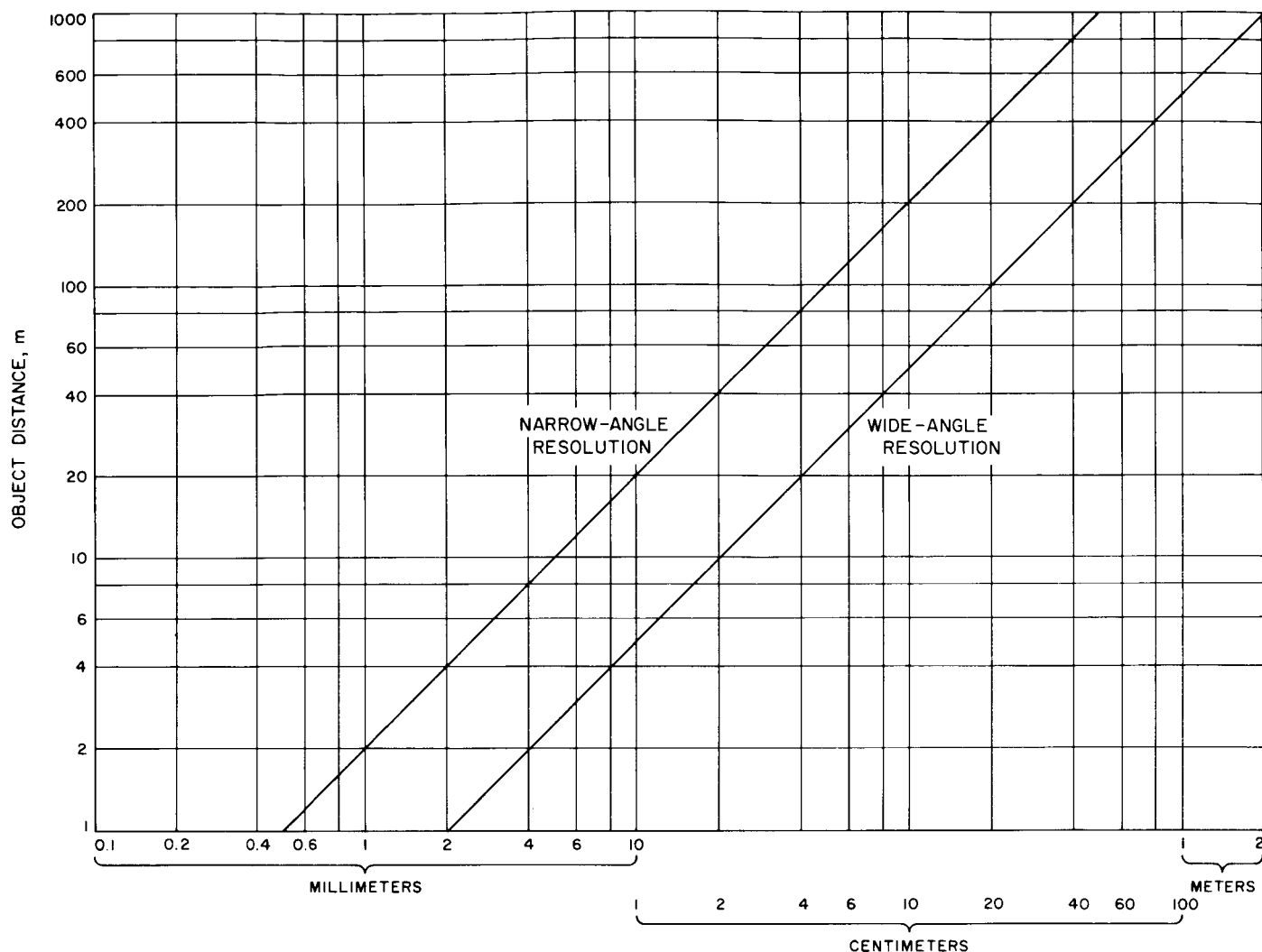


Fig. 14. Survey TV resolution

E. Alpha-Scattering Experiment

The alpha-scattering experiment is provided to analyze the chemical composition of the lunar surface at the spacecraft landing point. This is accomplished by measuring the energy spectra resulting from Rutherford-scattering of alpha particles from the heavier elements, and nuclear-scattering and (α, p) reactions from the lighter elements. The instrument, shown in Fig. 16, is mechanically deployed to the lunar surface after landing. A collimated beam of monoenergetic alpha particles from radioactive curium (Cm^{242}) is used. Particles scattered from the sample target are measured by semiconductor detectors placed at an angle approaching 180 deg (Fig. 17). The pulses from the detectors are amplified, analyzed electronically, and telemetered to Earth where

the energy spectrum of the scattered particles is reconstructed (Fig. 18).

F. Micrometeorite Experiment

The micrometeorite instrumentation is designed to measure the flux, momentum, and gross trajectory of particles at the lunar surface in the vicinity of the spacecraft. The instrument (Fig. 19) contains three basic sensors—an impact plate with an effective area of 1,000 cm^2 , and two thin-film capacitors. An acoustic transducer bonded to one side of the impact plate picks up signals related to the momentum of the striking particle. The capacitors consist of a thin film of dielectric bonded to each side of the impact plate and covered with a layer of conducting material. Penetration of either capacitor

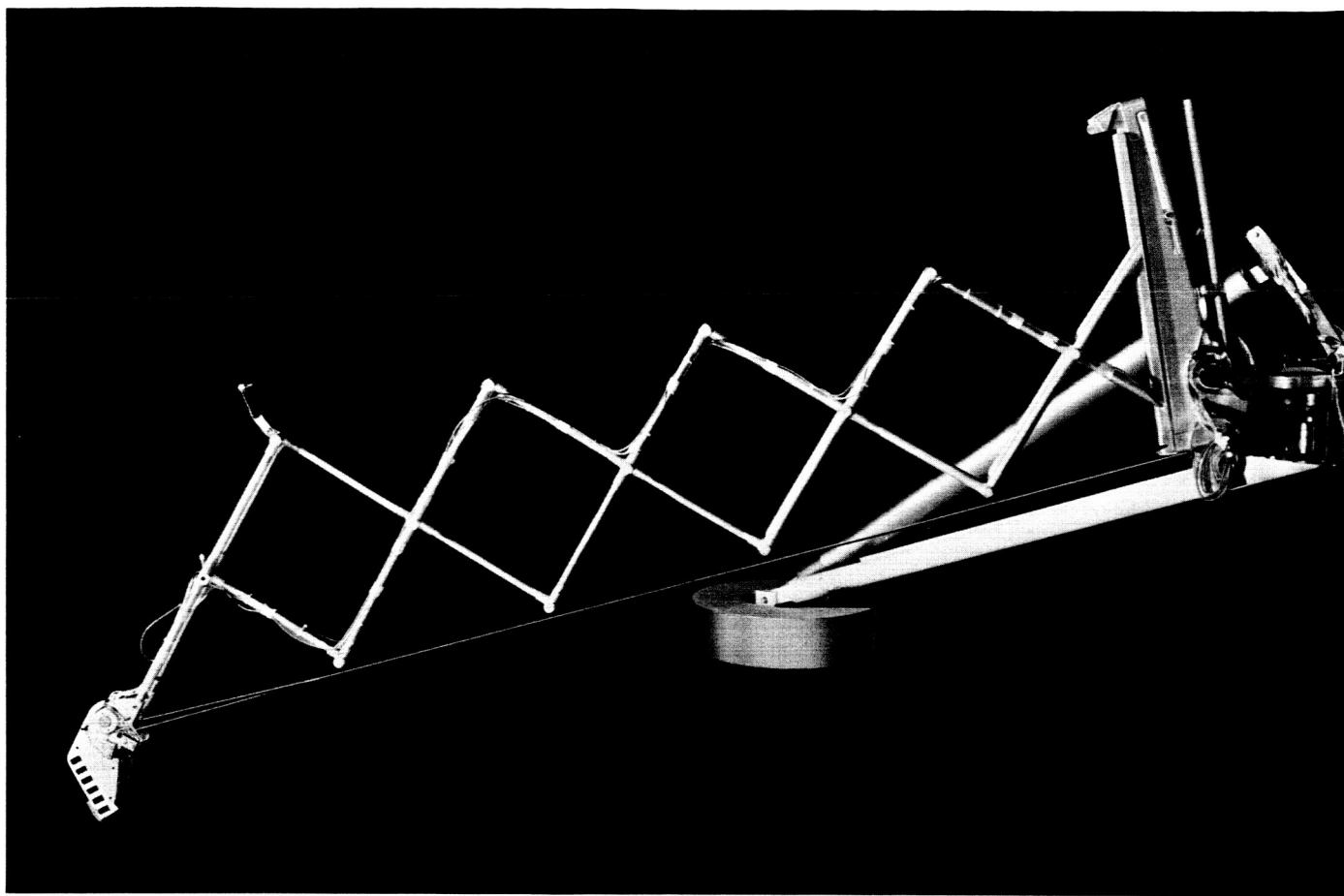


Fig. 15. Soil mechanics surface sampler

produces a pulse which is related to the particle energy. Pulse height analysis of both the acoustic signal (momentum) and the capacitor signal (energy) enables the number, mass and speed of particles to be determined. The acoustic transducer is sensitive to particles with momentum greater than 10^{-5} dyne-sec, while the capacitor films have been shown to be sensitive to energies greater than that of a 10^{-13} gram particle with a speed of about 1 km/sec (10^{-3} erg).

G. Seismograph Experiment

The seismograph experiment is designed to determine the presence of moonquakes, the effect of temperature cycling on surface materials, meteorite impacts, and the elastic properties and structure of the lunar surface. The instrument is a coil-magnet velocity transducer. The magnet acts as a spring-supported mass (natural frequency of 1 cps), and the coil is mounted on the sensor housing (Fig. 20). The seismometer is rigidly attached to

the spacecraft and designed to operate at angles up to 15 deg off vertical. The frequency characteristics of the sensor are shown in Fig. 21. Tests with the prototype instrument indicate a sensitivity of approximately $0.1 \text{ m}\mu$ displacement at 1 cps along the vertical axis for a signal-to-noise ratio of 1. The frequency response of the sensor and amplifier covers the range from 0.05 to 20 cps at all gain levels (spacecraft resonance partially blocks response in the 10- to 20-cps passband).

H. Touchdown Dynamics Experiment

The touchdown dynamics experiment provides a history of the linear and angular motion of the spacecraft after contact with the lunar surface. To accomplish this, 24 sensors are provided. The sensors are located on the spaceframe, as shown in Fig. 22, and measure the following parameters:

1. Three orthogonal components of linear acceleration and roll rates of the main spaceframe structure

2. Magnitude of loads in the landing leg structures from which force vectors on each foot pad are computed
3. Position of each landing leg relative to the space-frame

4. Time of contact with the surface of each foot pad and crushable block

Primary data, such as linear accelerations in body axes, roll rates, leg structure relative locations, and forces in leg structures, are expected to be accurate to the minimum resolution element of $\pm 2\%$.

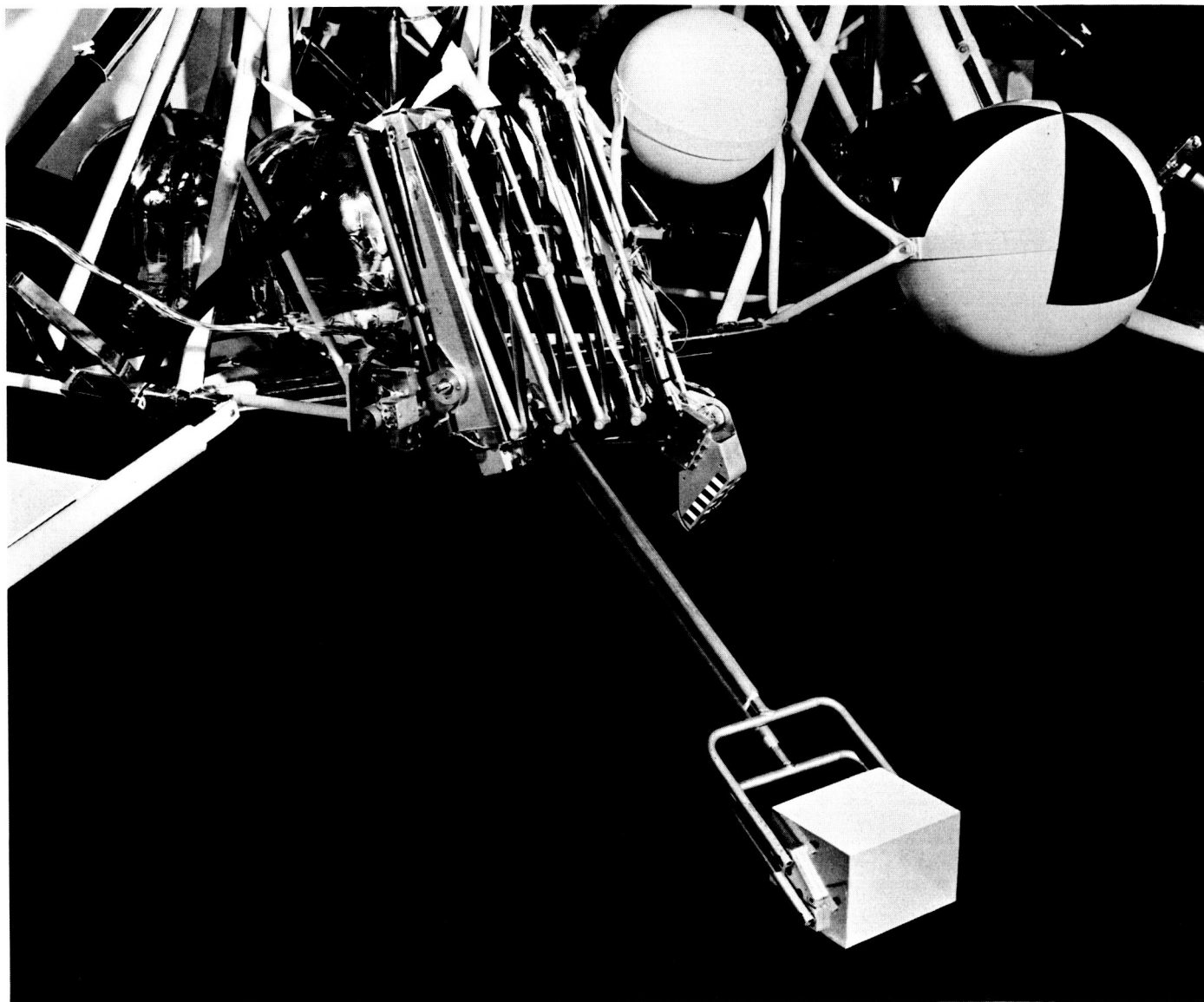


Fig. 16. Alpha-scattering deployment

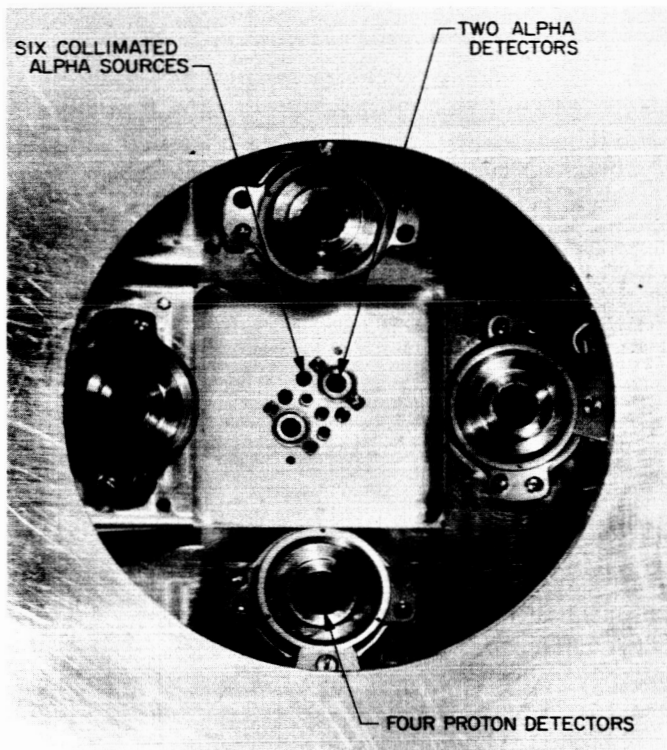


Fig. 17. Alpha-scattering sensor

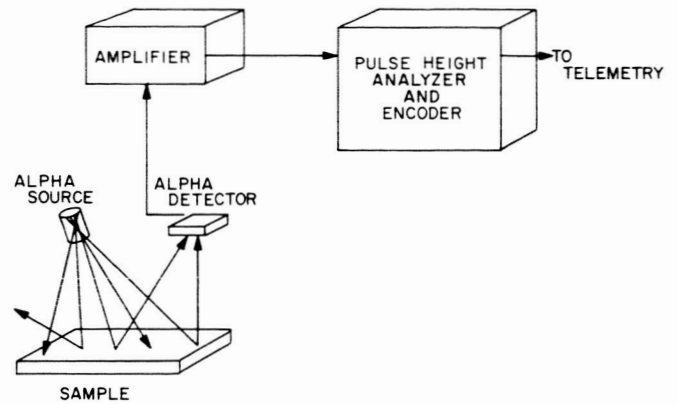


Fig. 18. Alpha-scattering operation

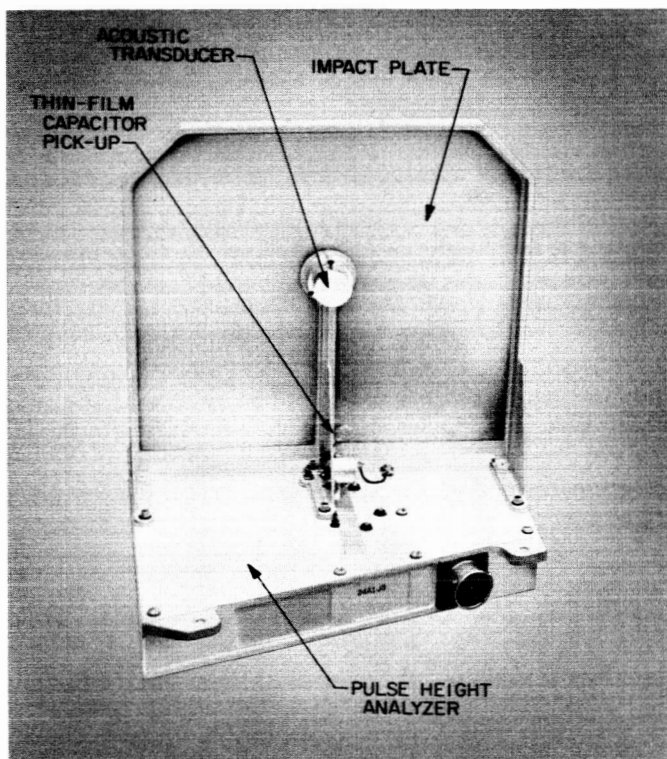


Fig. 19. Micrometeorite detector

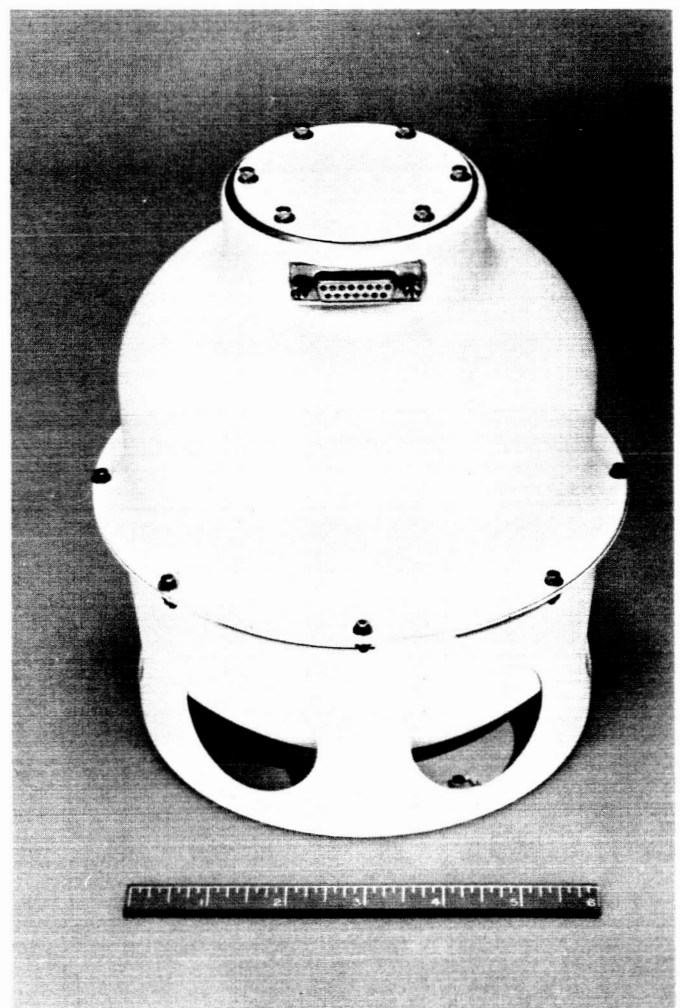


Fig. 20. Seismometer

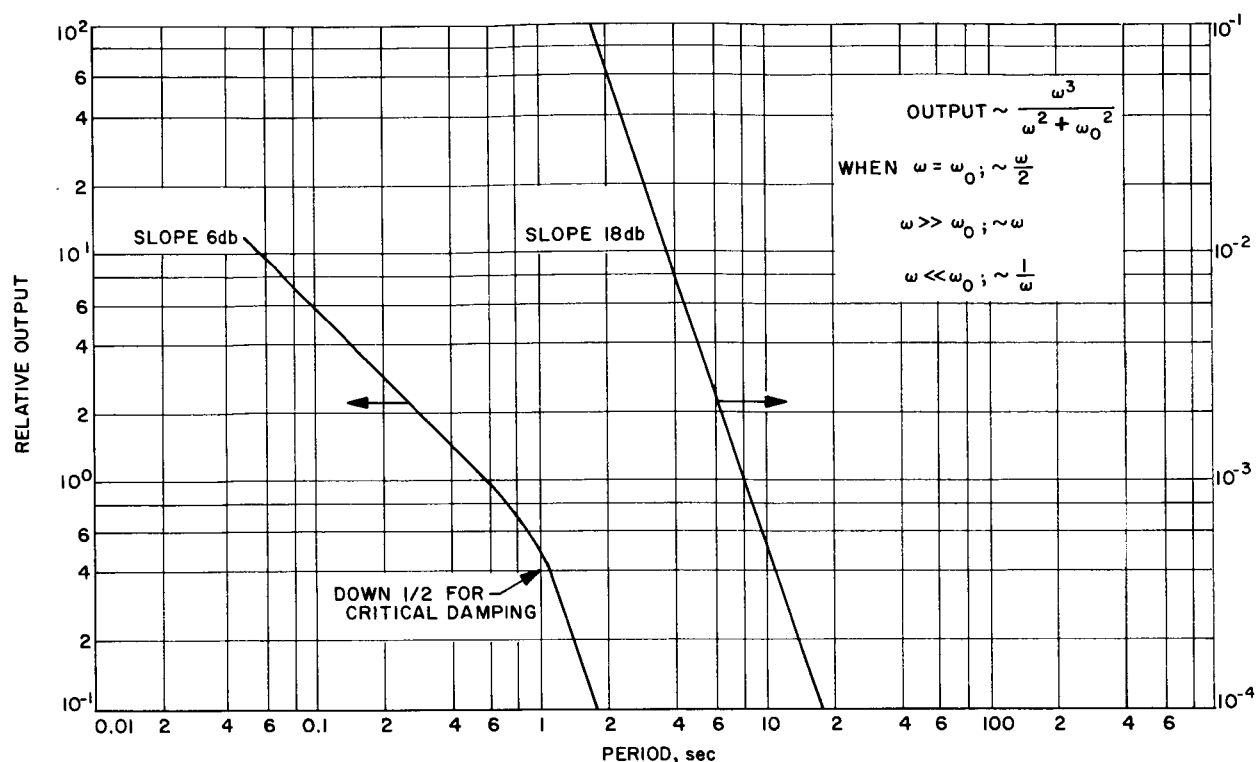


Fig. 21. Seismometer frequency characteristics

VI. MISSION SIGNIFICANCE

The ability of *Surveyor* to enhance our knowledge of the lunar environment is principally a function of the scientific payload. However, despite the system-development objective of the first four missions, much can be learned about the lunar environment from the successful landing of a spacecraft and its engineering payload. This information is in addition to that which may be concluded from a successful landing, that the lunar environment is not far different from that assumed for design of the spacecraft system.

A. Spacecraft 1-4

Analysis of only the engineering telemetry obtained during descent, touchdown, and postlanding operations may yield scientific information. As might be expected, the amount of information would be small, since the engineering measurements are mainly concerned with determining internal operations of the spacecraft and

not lunar properties. However, certain data could be gathered about the lunar surface from a successful landing of Spacecraft 1-4.

The single survey camera on the first four *Surveyor* flights will be the only payload item to collect measurements of lunar surface features after touchdown. From these measurements, the following analyses are expected:

1. Qualitative determinations of small scale surface roughness, slopes, and dust layers, with a maximum resolution exceeding 1 mm next to the spacecraft
2. Photometric, colorimetric, and polarimetric properties of the visible area
3. Discrimination of surface units in the landing area by their light scattering properties

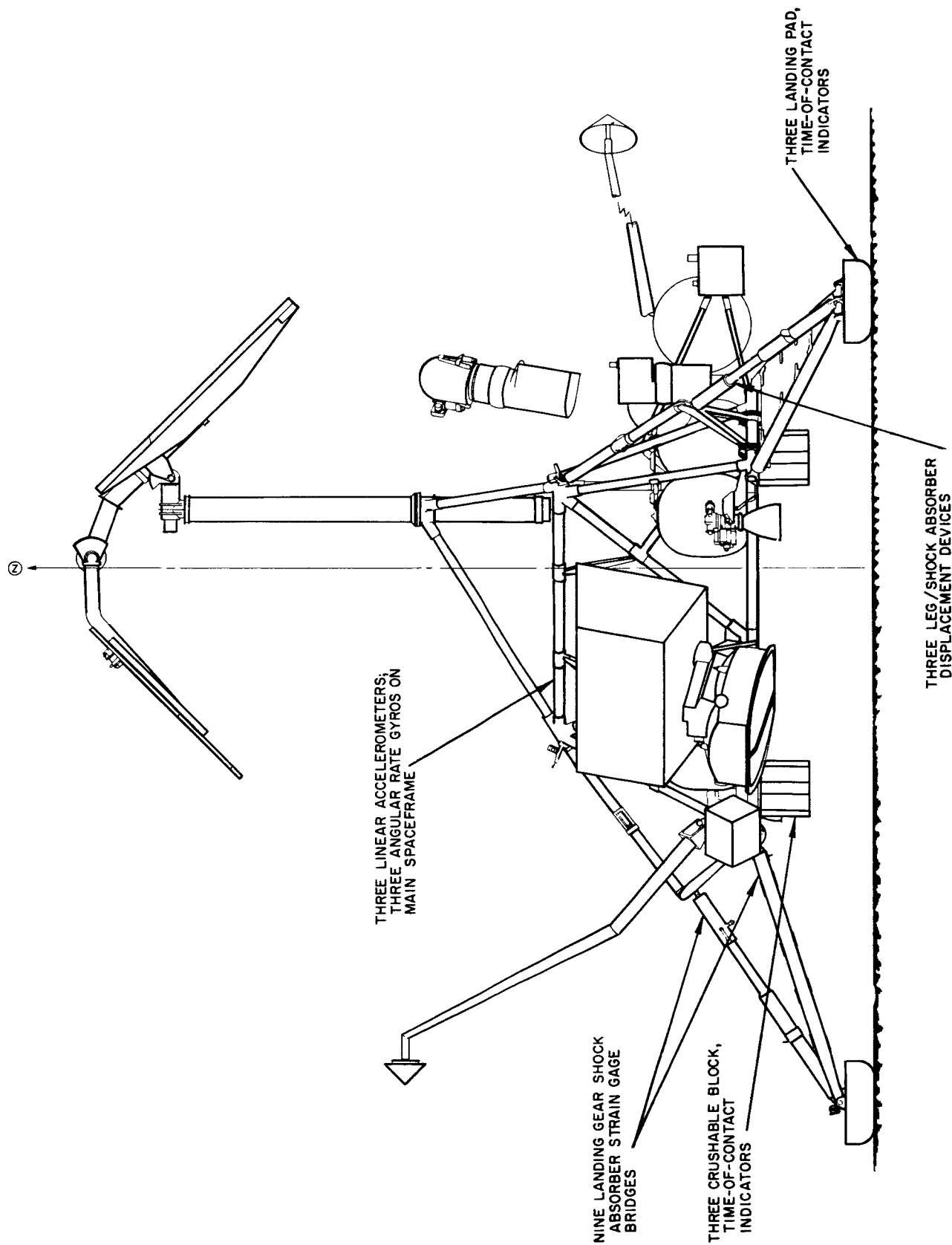


Fig. 22. Touchdown dynamics installation

4. Classification of the observable, discriminated lunar surface units by light-scattering and other measurable physical properties
5. Correlation of discriminated units with the geologic interpretation of the observable lunar surface, and with any visible disruption of the immediate area by the landing gear
6. Differential photometric measurements of the observable terrain, and determination of the relation between the small and large scale lunar photometric function
7. Measurement of lunar surface relief by:
 - a. Photometric measurement of lunar surface features in the observable vicinity of the spacecraft
 - b. Change in feature shadows with time
 - c. Comparison with spacecraft measurements in the immediate vicinity of the spacecraft

Provided there is no interruption in the transmitted signal during the spacecraft touchdown phase, three fundamental surface properties can probably be inferred from the telemetered dynamic data. These properties are surface hardness or bearing strength, slope, and coefficient of friction.

Spacecraft attitude can be obtained from tracking data (which indicates the location of the spacecraft on the lunar surface) and the angular relationship of the solar panel and high-gain antenna with respect to the Sun and Earth. If the spacecraft landing legs have not deformed and they are sitting on a plane surface, the slope of this surface with respect to the local vertical can be inferred to an accuracy of ± 3 deg. The use of the television system to obtain a star fix would increase the measurement accuracy to ± 1 deg. If the surface slope and spacecraft attitude and velocity are known, then a gross estimate of surface hardness can be made; i.e., the hardness can be ascertained to be above 50 psi, or if below 50 psi, an order of magnitude estimate can be made.

If the lateral velocity at touchdown is known to an accuracy of $\pm 1/2$ fps and there is indication of a hard surface by the rise-time of the shock absorber function, then the gross characteristics of surface friction can also be derived (0, 0.5, 1.0). Dust may be normally present in the lunar atmosphere or appear as a temporary cloud stirred up by the *Surveyor* spacecraft. As no measurable effect is expected to be attributable to galactic dust, all

observable effects can be credited to lunar dust. These effects, if present, will be detected by the solar panel, the television, and possibly the other photo sensors such as the Canopus sensor and the primary and secondary Sun sensors. After touchdown, if the rate of decrease of solar panel power output is greater than the temperature coefficient would indicate, then lunar dust is probably coating the panel. This change in power output will give an indication of the nature and extent of the lunar dust. The TV survey camera will obviously be a very efficient sensor for dust by virtue of its ability to observe the spacecraft and the surrounding area. In addition, if dust collects on the filters or lens object glass, the optical system transmission will be seriously degraded. It may be possible to differentiate dust from electronically caused degradation (and hence, the rate of dust accumulation) by studying the history of the degradation.

Micrometeorite detection is associated with television-observable effects and catastrophic failures. While no apparent damage due to micrometeorite impact was discovered on the *Mariner 2* mission, the sudden cracking of an optical element such as a filter or a sudden change in solar panel output (failure of one string of solar cells causes a 3% change in output) could be attributed to an impact.

B. Spacecraft 5-7

The successful landing and operation of the scientific payload on Spacecraft 5-7 would greatly enhance present knowledge of the lunar environment. In gathering this information, the scientific payload presents many opportunities for cross-correlation of data derived from the six experiments. Of particular significance will be the use of the television to observe the operation of other experiments such as the surface sampler, alpha-scattering, and touchdown dynamics.

Surveyor experiments are expected to yield detailed measurements of the lunar surface relief and physical properties in the immediate vicinity of the spacecraft. While this data may be adequate to certify the *Surveyor* landing point as acceptable for the Apollo Lunar Excursion Module (LEM), the first seven *Surveyor* missions could not certify a LEM landing site (1,600 m radius) to the current standards established by the Office of Manned Space Flight. Certification of a LEM landing site is not possible until capabilities for detailed contour mapping and for testing surface bearing strength at multiple locations within the site are provided.

C. Television-Survey Experiment

In addition to the data capabilities described for the single survey camera in the engineering payload (Spacecraft 1-4), stereoscopic observations are made possible by the use of a second survey camera. This capability will permit accurate photogrammetric measurements of slopes and location of objects. The maximum limit for accurate mapping is expected to be 24 m, with an anticipated minimum limit of 12 to 15 m from the spacecraft for measurements with an error of $\pm 5\%$. With these limitations, however, geometric measurements of the distribution and size of objects can be made and used in the preparation of topographic maps. These maps will serve as the reference framework for the comparison of visual and other measurements. As a result, an understanding of the geological history of the *Surveyor* landing site is anticipated, permitting extrapolation of data to other lunar areas.

D. Soil Mechanics Experiment

In addition to making detailed topographic measurements, the surface sampler will be able to determine mechanical and physical properties of the lunar soil. Estimates of surface bearing strength under static loading conditions may be obtained by monitoring the penetration of the scoop during the application of two static force ranges, 1.5 and 75 psi. Measurements of displacement, horizontal force, and vertical load during shear tests with the sampler will confirm and extend the static bearing strength data. If the lunar surface material is impenetrable, some estimate of frictional behavior will be obtained. If the material is penetrable, trenching can be carried out to a maximum depth of 20 in. below a nominal horizontal surface, permitting bearing capacity tests at successively lower levels.

Four basic ranges of dynamic operation, in addition to variation of drop height and sampler extension, provide a very large range for measurements of surface material dynamic behavior. Deceleration vs time-histories, and impact velocity measurements will:

1. Classify the lunar surface material as granular, porous, or solid
2. Determine, to an order of magnitude within a very large spectrum of mechanical properties, the quantitative mechanical properties of the surface in terms of modulus of elasticity and yield strength (Fig. 23)

E. Alpha-Scattering Experiment

The alpha-scattering instrument is capable of detecting all elements present in amounts greater than 1 at. % except hydrogen, helium, and lithium. However a difficulty in interpreting alpha-scattering data arises from the use of only chemical criteria to erect a genetic classification scheme that will characterize the lunar rocks and establish the extent and manner of differentiation. An additional problem is posed by the probable significance of one or more samples in the close vicinity of the spacecraft, with respect to the large-scale composition of the lunar surface. In spite of these difficulties, six independent studies concerning possible geological information to be derived have concluded that the instrument will permit distinction between major hypotheses of lunar origin (meteoritic accretion, differentiation, and basalt). It was also concluded that the instrument would be able to distinguish between meteoritic and igneous rock material by virtue of the silicon-to-sodium ratio observed.

F. Micrometeorite Experiment

The *Surveyor* micrometeorite instrumentation is designed to measure flux, momentum, and gross trajectory of particles at the lunar surface in the vicinity of the spacecraft. From these data, primary micrometeorite particles impacting the lunar surface should be distinguished from ejecta particles thrown out by the impact. This will provide insight into the enhancement of the primary influx rate by the secondary ejecta phenomenon at the lunar surface; assist in the study of the nature of the surface and the evolutionary processes on the Moon; investigate the contribution of lunar ejecta-to-dust particle distributions in space; and evaluate the hazard confronting manned and unmanned explorations of the lunar surface.

While the instrumentation is capable of showing that a micrometeorite hazard does exist on the lunar surface, it is doubtful that it can show that such a hazard to astronauts does not. There are at least two reasons for this: first, the product of the detector area and the anticipated experiment lifetime is not sufficiently large, compared to the exposure area and sampling time of interest to Apollo (200 m²-yr, i.e., less than 1% probability of puncturing a vehicle with 10 m² surface area); second, meteorite impacts tend to come in showers associated with the periodic motion of micrometeoroid swarms around the Sun and measurements may be made during a relatively quiet period.

G. Seismograph Experiment

The *Surveyor* seismometer will clearly determine whether or not the Moon is seismically active. The degree of seismic activity of a planet depends on the rate at which thermal energy is converted into mechanical energy. The rate of conversion depends on the body's thermal regime which, in turn, is fixed by the concentrations of radioactive elements, initial temperature, and rate of tidal energy dissipation. A determination of the presence of lunar seismicity will permit first order conclusions regarding the nature of the interior of the Moon and its possible past history. Observations will determine whether there are natural elastic disturbances within the Moon resulting from thermal processes or from meteoritic impact and will permit fixing of the background noise level.

The existence of distinct seismic events in the Moon would yield a variety of additional information. The travel times of seismic body pulses and the dispersion and absorption of seismic surface waves, can be used to infer the internal constitution of the Moon. While it is not possible to derive travel times from a single record, it will be possible, by assuming a rough travel-time curve, to obtain information regarding the distance of the seismometer from the source, the presence or absence of a major shadow zone which would indicate a liquid lunar core, focal depth of lunar quakes, and rough estimates of seismic energy release.

By extrapolation to other lunar areas of interpretations based on seismic data collected at the *Surveyor* landing site, seismology can yield only qualitative information regarding near-surface structure. Ideally, the seismic wave records might indicate a highly homogeneous waveguide. This would be an indication of homogeneity over large areas near the landing site and extend to depths on the order of kilometers. Alternately, highly cluttered signals would suggest many scattering centers and, as a result, great inhomogeneity within the upper layers. Such information does not provide the particular details required by Apollo, but should be useful in constructing improved models of the lunar surface.

H. Touchdown Dynamics Experiment

The spacecraft and touchdown dynamics instrumentation will provide data on motion of the spacecraft reference axes, bearing and shear strength (coefficient of friction) of the lunar surface, penetration of the landing pads into the surface, and surface contours on approximately the scale of the spacecraft foot spacing (10 ft).

The initial velocity of the spacecraft at touchdown will be calculated using doppler radar and rate gyro data during the free-fall period after vernier shutoff. Linear accelerations, velocity, and displacement from the accelerometer data will be combined with data from the rate gyros to define the motion of the spacecraft center of gravity in the lunar inertial reference system.

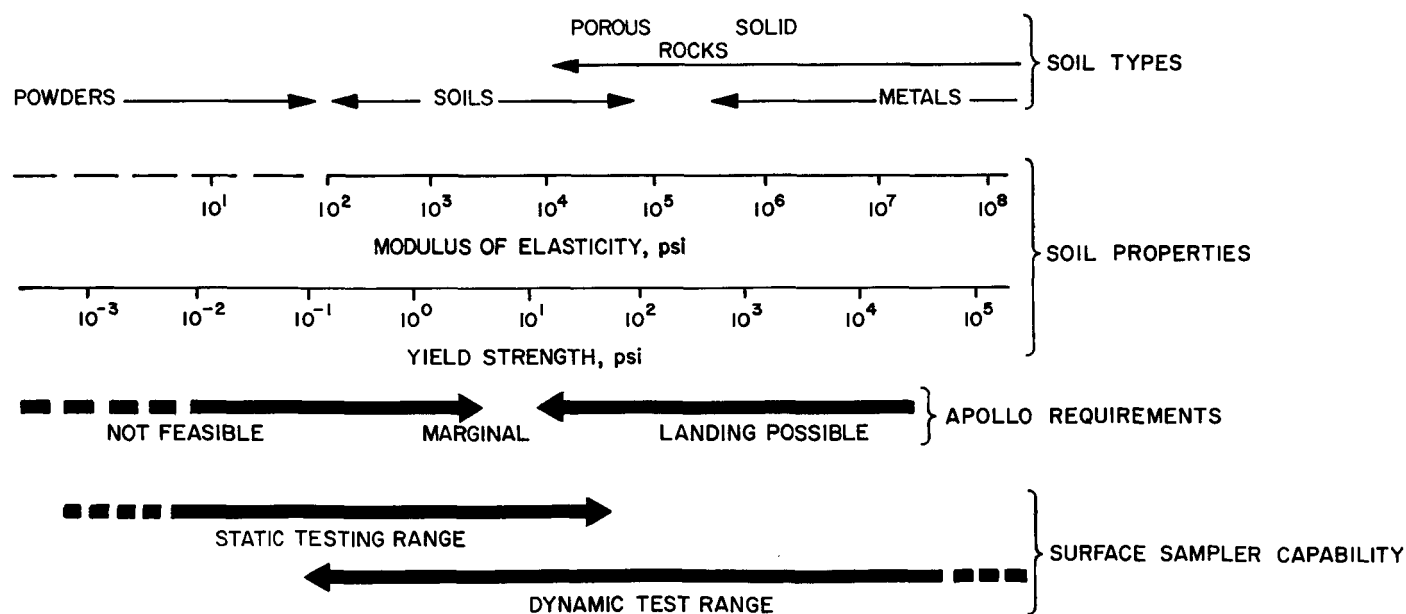


Fig. 23. Surface sampler capability compared with Apollo requirements and properties of materials

The strain gages and position indicators on the landing gear will yield information regarding the bearing strength and shearing resistance or coefficient of friction of the lunar surface when analyzed with the spacecraft center of gravity motion data.

Information relative to the penetration of the impacting bodies (spacecraft footpads and crushable block)

into the lunar surface is expected from an analysis of the load components parallel and normal to the direction of the resultant velocity vectors of the impacting bodies. Six points of relative elevation of the lunar surface will be established by noting the position of each footpad and crushable block at the instant of impact. If the surface is relatively impenetrable, the motion of the footpads after touchdown will describe the surface contour.

VII. FOLLOW-ON MISSIONS

Surveyor follow-on missions (Spacecraft 8-17) are being studied to determine how best to proceed with unmanned lunar exploration while fulfilling the site-certification requirements of the Apollo program. Initiation of follow-on missions is scheduled for calendar year 1967. As might be expected, performance improvements are contemplated for all systems involved in the *Surveyor* project. For example, it is expected that the Centaur launch vehicle system will be capable of injecting substantially larger payloads by the addition of fluorine to the liquid oxygen carried in the Atlas; the capability of the DSN will be enhanced by the addition of 210-ft D antennas at its stations; the SFOF will be expanded by the addition of improved television data processing equipment, and multimission control facilities; and finally, the spacecraft subsystems will be upgraded to provide increased reliability and payload carrying capability.

While the goal of *Surveyor* follow-on missions is the acquisition of a thorough understanding of the lunar surface and its history over the area of concern to the Apollo mission, the specific site survey requirements of Apollo pose a formidable problem for any project. For example, the lunar area of Apollo interest lies between latitudes of ± 10 deg and longitudes of ± 60 deg. It is clear that even if *Surveyor* could properly survey the lunar area visible to the horizon on a spherical Moon,

over a million spacecraft would be required. We must, therefore, narrow the area of concern or develop an acceptable process for characterization of lunar areas and extrapolation of a few measurements to these areas with high confidence. This latter approach is still under study and involves data obtained from and expected to be obtained from Earth-based observations and lunar probes such as *Ranger*, *Orbiter*, and *Surveyor*.

If the area of concern is narrowed to that contained in a few Apollo landing sites, an acceptable system for site investigation to standards of the Office of Manned Space Flight appears feasible. One such system involves a *Surveyor* payload which, when landed on the Moon, disembarks and roves over the potential Apollo landing site conducting soil-bearing strength and topographic surveys. The *Surveyor* Lunar Roving Vehicle would weigh approximately 150 lb and have the ability to traverse terrains whose characteristics are not acceptable for Apollo landing sites. It would probably be completely controllable from Earth, able to survive the lunar night, and have a range of greater than 30 km.

While the selection of follow-on mission payloads and specific experiments has not been completed, there is growing evidence that a significant contribution can be made by *Surveyor* to Apollo landing site selection and to a better understanding of our nearest celestial neighbor.

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